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RESEARCH NEEDS RELATED TO INTERNAL DOSIMETRY

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ABSTRACT

There are several important techniques of internal dosimetry for use with uranium mine and mill workers: personal radon daughter dosimetry, uranium content of urine, whole body counter to evaluate the uranium in lung burden, and assay of uranium in biopsy or autopsy tissue samples. There are problems with each of these techniques and further research is required in internal dosimetry (as well as the alternative of monitoring exposure levels). This research should be aimed at improved or supplementary dosimetry techniques, enhanced theoretical interpretation of dosimetry results and fundamental research not directly related to the techniques mentioned above.

Proposals for research as presented by the working group in this report should be considered by funding organizations concerned with internal dosimetry as it relates to the uranium mining industry, and, since this report was first presented, AECB has proceeded with related projects.

Key words: Personal dosimetry; Alpha-particle dosimeters.

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INTRODUCTION

This is a report prepared by a working group on behalf of the Joint Panel for Occupational and Environmental Research for Uranium Production in 1985 and accepted by the Panel for publication at its summer meeting in 1986.

For technical reasons, general publication of this report has been delayed although it has been available to all Panel members from the date when it was approved. The Panel has been gratified to note that a number of the recommendations for further research made in this report have already been accepted by the Atomic Energy Control Board. Several of these have already been through the funding procedure and reached the stage where work is now in progress. The Panel wishes to record its appreciation of the prompt and full consideration which was given by the Board to its report. This has made the efforts put in by the members of the working group well worth while.

OVERVIEW OF INTERNAL DOSIMETRY TECHNIQUES FOR URANIUM MINING/MILLING

There are four important techniques which are relevant for use with uranium mine and mill workers. These are:

1. Personal radon daughter dosimetry.
2. Assay of uranium content of urine samples.
3. Use of a whole body counter to evaluate the uranium in lung burden (and as a retrospective method of estimating large lifetime radon daughter exposure by evaluation of ^{210}Pb levels in bone).
4. Assay of uranium in biopsy or autopsy tissue samples.

Problems arise in the interpretation and/or evaluation of risk associated with each of these dosimetry techniques. Some of these are considered below:

1. Risk estimates associated with radon daughter exposures may vary over a very wide range depending upon the method of assessment used. The main

source of information is epidemiological studies of excess lung cancer incidence which have been conducted for large groups of miners or former miners in the United States, Canada, Czechoslovakia, France, Scandinavia and other countries. Many of these studies relate to uranium miners - others were conducted in coal, fluorspar and metal mines where significant quantities of radon were present. Only in uranium mines was it usual to measure radon and/or radon daughter levels during the period in which the miners who were studied accumulated the majority of their dose. Even in uranium mines, readings were very few and infrequent. Operators required to report periodic radon measurements would obviously tend to take these at times and locations where the observed values would be lower than average. This has probably led to a built-in bias in the studies such that exposures were greater than has actually been estimated and consequently the calculated risk factor per unit exposure is likely to be unduly high.

The alternative route for the evaluation of risk is to use calculations based on dosimetry, i.e., the radiation energy deposited in the cells of the bronchial epithelium in which most such cancers originate. The radon daughter concentration controls the energy released per cubic metre of air per hour and constitutes the exposure level of the individuals concerned. The cellular dose depends on many factors, both physical and biological. Physical factors include the degree of equilibrium between the different radon daughters, the proportion of daughters existing as unattached ions and the AMAD of the dust particles to which other ions are attached. Biological factors include rate of breathing, whether by nose or mouth, the structure of the bronchial tree, the rate of ciliary clearance, the thickness of the mucosal layer, the distribution of the target cells, etc. At least four different models for

a standard lung have been developed and used in dose calculations. These are the I.C.R.P. model and lung models developed by Jacobi and Eisfield, James and Birchall, and Harley and Pasternack. (The I.C R.P. lung model is currently being revised and Dr. John Johnson of A.E.C.L. is Canadian representative on the committee responsible for updating it). All lead to significantly different conclusions regarding probable cellular doses to the lining cells of the bronchial epithelium.

Because of these various uncertainties there is considerable difficulty in assessing the true risk associated with any measured radon daughter exposure, and only limited agreement between different authorities as to the validity of such risk assessments, when made.

2. In the past it has usually be assumed that kidney damage associated with the chemical toxicity of uranium is more important than radiation damage resulting from its radioactivity. At one time large quantities of uranyl nitrate were prescribed medically for diabetes. (Doses of up to 925 mg three times per day, continued for a year, are reported in Vol. XXXVI of the Handbook of Experimental Pharmacology), but in the 1940's animal and other studies carried out as part of the Manhatten Project indicated that quite small amounts of uranium could cause nephrotoxicity and the U.S. Nuclear Regulatory Commission currently (1978 standard) sets an upper action level for uranium in urine of 30 µg/L for uranium mill workers, on the assumption that levels above this may lead to kidney damage. A recent paper by Thun, et al. (Scan. J. Work Env. Health 1985) has shown significantly higher levels of amino acid excretion among uranium mill workers when compared with cement plant workers. Animal experiments suggest that kidney damage from low level chronic exposure to uranium is largely reversible but this cannot be regarded as definitely established.

In the case of ingested uranium the radiation hazard is chiefly to

bone surfaces and tends to be associated more with insoluble uranium which is not rapidly cleared into urine. A critical factor in assessing the risk associated with uranium dust inhalation is therefore the solubility of the uranium compound concerned. In the case of yellow cake this depends not only upon the chemical form but also on the physical state. A study by Eidson et al. (Health Physics 1980) showed that marked variations in solubility could be produced by changes in dryer temperature.

Such variations mean that uranium in urine measurements are a poor indicator of total uranium body burden and an even poorer indicator of the associated health hazard.

3. Uranium is a difficult isotope to evaluate accurately using a whole body counter and the limiting sensitivity which is achievable in practice with conventionally designed counters is of the same order of magnitude as the I.C.R.P. a.l.i. Whole body counters therefore provide a valuable monitoring procedure if an unusually high uranium intake occurs, but are not sufficiently sensitive to record intakes significantly lower than this and to aid in the development of effective control procedures at these levels.

Whole body counters have one other important application. Skeletal ^{210}Pb counts can be used to assess lifetime radon daughter exposures as daughters which are totally ingested will decay into lead-210 and be primarily incorporated into bone tissue. There are two limitations to this technique - the first is inadequate sensitivity and the second is uncertainty about how far the total ^{210}Pb burden of the body has been reduced by radioactive decay and natural elimination. (This will obviously depend upon the total time which has elapsed since the original radon daughter exposures.)

4. By its very nature the analysis of biopsy or autopsy samples may be of

value in establishing or confirming acceptable limits of exposure, but will not help in limiting the exposure of individuals concerned to levels which are deemed to be safe.

It follows that while all four of the internal dosimetry techniques reviewed above have an important part to play in effective radiation control in the uranium mining industry, none of them is adequate to provide full and explicit information for accurate risk assessments, and there is a great need for additional research which will help to reduce some of the ambiguities associated with each of these four techniques.

It is difficult to predict the extent to which available techniques for internal dosimetry will be improved over the next few years. Procedures such as personal radon dosimetry are likely to be greatly improved with respect to cost, bulk, weight, complexity and perhaps also sensitivity of the devices used; while with some other procedures, it is not easy to visualize any major breakthrough which will lead to significantly enhanced performance. At present, many radiation control procedures are best carried out by monitoring exposure levels rather than received doses. This is likely to continue for many years and, in looking to research needs related to internal dosimetry, it is necessary to recognize that in some cases research devoted to improved monitoring of exposure conditions is likely to be of more immediate value. Such research is not discussed here as it lies outside the scope of the present report. Even where research into monitoring procedures for exposure control should have the higher priority, there would be no justification for not actively pursuing the promising lines of research in internal dosimetry which are discussed further below.

RESEARCH NEEDS RELATED TO INTERNAL DOSIMETRY

These can be classified into three general areas:

A. Research related to improving or supplementing the actual dosimetry techniques reviewed in the last section.

B. Research related to aiding in the theoretical interpretation or risk assessment associated with results obtained by means of these dosimetry techniques.

C. Fundamental research not directly related to any one of the dosimetry techniques considered above.

Your working group suggests that the following specific projects should be considered to warrant priority attention in each of these three areas. Where significant studies are already in progress, or at an advanced stage of planning, we have attempted to indicate this.

A1) A field intercomparison of the reliability and accuracy of CEA and Alpha-Nuclear personal radon daughter dosimeters has been initiated by the CANMET Laboratories. This should be continued and extended to also encompass studies of passive radon daughter dosimeters.

A2) A study of variability in the solubility of yellow cake samples from a single specific Canadian uranium mill both in vitro and in vivo should be initiated. Canadian uranium mills generally have a large throughput and yellow cake processing and drying is carefully controlled on an ongoing basis. It would be of considerable value in interpreting uranium in urine measurements if it could be demonstrated that the large day-to-day variations in solubility reported for some small U.S. mills do not arise to the same extent in Canadian mills.

A3) Studies of improved technology for whole body counting (the use of semi-conductor type detectors and/or the introduction of computerized techniques for improving signal to noise ratio) are in progress at several centres including the RPB in Ottawa. These should be completed before further work is planned.

A4) Data from biopsy or autopsy tissue samples can only be meaningful when an adequate supply of such samples is available. Your working group strongly urges renewed attempts to establish a Canadian uranium tissue registry and to encourage its acceptance by ensuring that tissue data is never used to preclude or discredit compensation claims by the families of workers who may have experienced significant uranium intakes.

B1) Epidemiological studies of lung cancer incidence among former Canadian uranium miners are being conducted by Dr. Mueller of the Ontario Ministry of Labour and Dr. Abbatt of Eldorado. In addition, the A.E.C.B. is attempting to establish adequate dosimetry data to carry out a study among former Newfoundland fluorspar miners. Your working group does not believe that there are any other exposed populations in Canada which would justify further epidemiological studies at the present time.

However, the working group does believe that additional research relating to the optimum lung model for dosimetry based risk assessments would be valuable at this time. A fundamental question is whether the risk associated with radon daughter exposures should be expressed in terms of a whole body dose equivalent in rems, which can then be added to any external gamma ray dose in rem to give an indicator of the overall risk to which the individual concerned has been exposed; or whether, because the nature of the risk is so different in these two cases, it may be better to retain separate numerical risk factors applicable to the two essentially different end point health detriments. An attempt to answer this question would itself be a worthwhile subject for a research type investigation.

B2) Animal experiments to re-evaluate the chemical toxicity of uranium appear to be warranted. It is suggested that these should concentrate on the extent and rate of recovery from tissue damage following nephrotoxic effects, and that a veterinary school should be encouraged to use nuclear

medicine techniques for evaluating renal function as part of such a study. Some experiments along these lines with rabbits have already been initiated by a group working with Health and Welfare Canada under the direction of Dr. A Gilman.

B3) Additional information relating to the solubility of uranium dust inhaled into the lungs (see A2) above), the metabolism of uranium compounds in the body and the biological half-life of such compounds; would all aid in the interpretation of data obtained by whole body counting of uranium. Attempts to estimate total lifetime radon daughter exposures from ^{210}Pb measurements would be improved by additional information on the rate of elimination of ^{210}Pb from the body. Further research in all these areas could prove highly valuable.

Basic research into the risk factors which should be associated with uranium dust inhalation is being undertaken in Canada by the A.E.C.B. Their study, which will be carried out in conjunction with a Canadian university veterinary school, will be based on exposing rats to known concentrations of uranium bearing dust and on evaluating the number of lung cancers resulting. Your working group believe that this will be a very valuable study and should be completed before other work along similar lines is planned.

B4) Interpretation of uranium in tissue assays requires detailed knowledge of the biological half-life and rate of elimination of the compounds concerned. Most of the research needs outlined in B3) above will therefore also be directly related to the proper use of tissue biopsy and autopsy data.

C. Fundamental research does not relate specifically to any of the four techniques of internal dosimetry being considered above. Possible projects discussed below are therefore numbered independently of these

four techniques.

C1) Most researchers have always concluded that the cells principally at risk for the induction of lung cancer are the stem cells of the bronchial epithelium. Some recent work has, however, suggested that other types of cell may be associated with the original lesion which initiates the malignancy. To confirm or reject this hypothesis your working group suggests that attempts be made to establish tissue cultures of the different types of cells which might be of importance, and to evaluate their radiosensitivities in-vitro.

C2) Critical factors in lung cancer induction are the effect of the thickness of the mucosal layer covering the bronchial epithelium and the efficiency of the clearing mechanism, usually referred to as the ciliary escalator. The mucosal layer thickness varies with age, occupational factors such as exposure to various irritants, and with personal habits such as smoking. It is typically close to the maximum range of the alpha-particles from radon daughters and in some instances it appears that only the high energy alpha-particle from ^{214}Po (7.7 MeV) would be capable of penetrating the entire layer and initiating a lung cancer. The Bragg curve for ionization density along the track of an alpha-particle indicates that the L.E.T. is highest at the end of the track just before the particle is brought to a standstill. If the cells are not killed outright it is in this part of the track where there is the greatest likelihood of initiating a malignancy in a cell which the particle is traversing. Turbulence in the mucosal layer will mean that alpha emitting dust particles or unattached ions are distributed throughout the mucosal layer and the point at which any alpha track originates is therefore not always on the outside surface of the mucosal layer. It does not appear that a great deal known about the distribution of the alpha emitting particles within the mucosal layer.

or about how the probability of cancer induction in a cell varies with the amount of ionization induced in it. Some simple studies relating to these key questions could probably be carried out using monolayer cell cultures exposed to very thin alpha emitting sources with variable thickness absorbers interposed to simulate different mucosal layer thicknesses.

CONCLUSIONS

These proposals are presented by the working group in the hope that interested organizations will consider funding some of the studies suggested thereby increasing scientific knowledge of the hazards associated with mining naturally radioactive ores.